



Sandia National Laboratories  
Los Alamos National Laboratory  
Savannah River Technology Center



# A Comparison of Four Methods for Determining Precipitable Water Vapor Content from Multi-Spectral Data

Karen Lewis Hirsch, Lee Balick, Christoph Borel\*,  
and Peter McLachlan  
Los Alamos National Laboratory



# Outline

- Motivation
- The four methods defined
- Some comparison images
- Conclusions
- Future Work



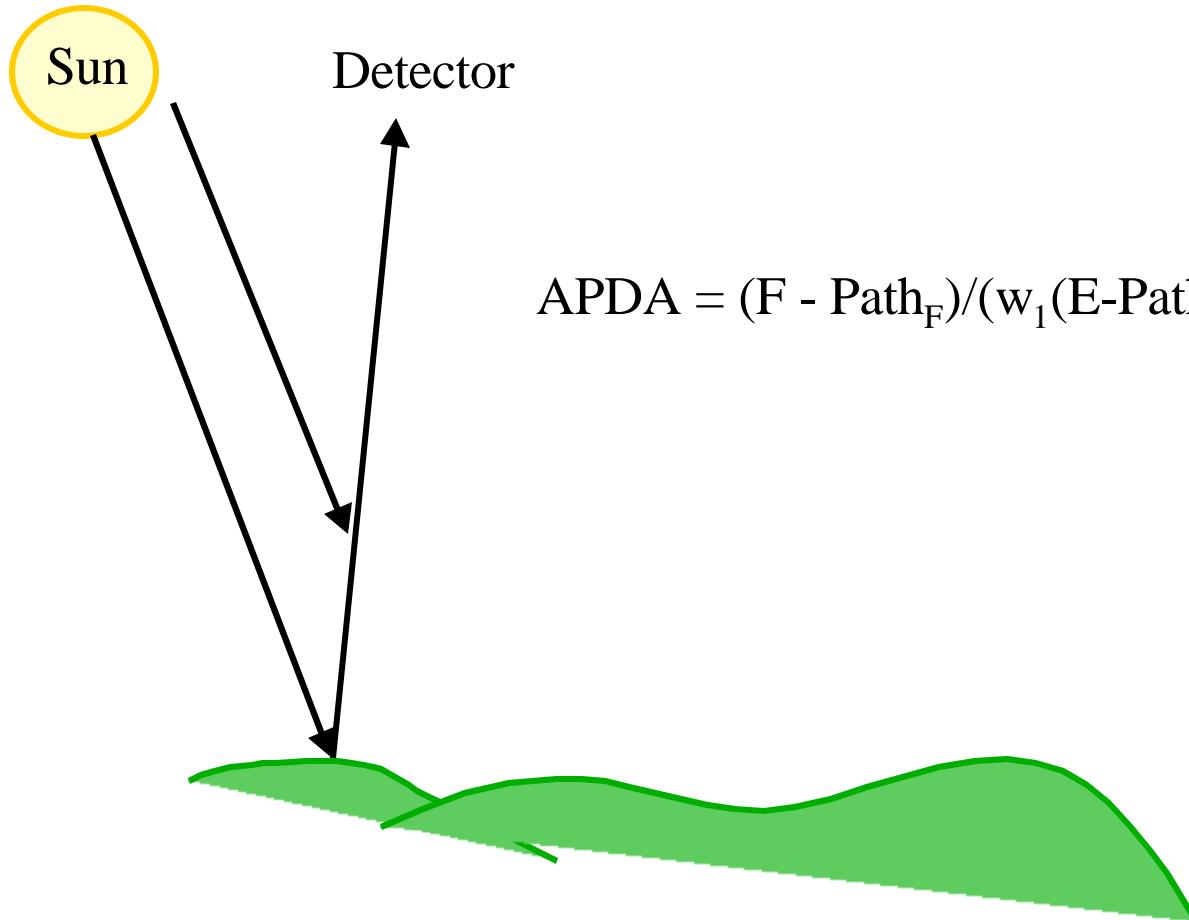
# Motivation

Atmospheric water vapor is important because:

- it effects apparent surface temperature values
- it can lead to over/under estimation of abundance of specific surface features
- can be used for studying greenhouse effect
- can be used to study atmospheric variability over small scales (e.g. turbulence)

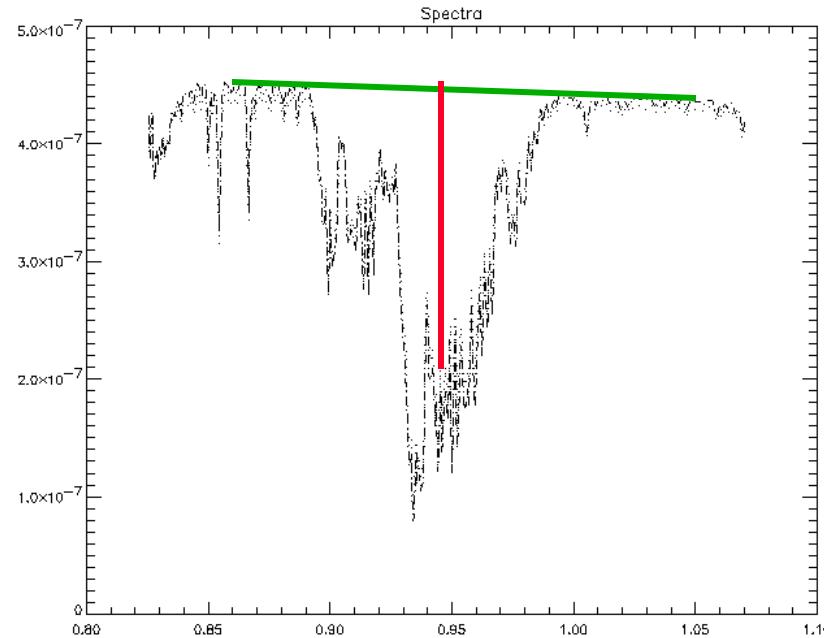


## Method 1: APDA - Atmospheric Pre-corrected Differential Absorption





# Method 2: CIBR - Continuum Interpolated Band Ratio



$$\text{CIBR} = F / (w_1 E + w_2 G)$$

Modtran 3.7 simulated spectrum



# Validation:

40 validation  
image/  
independent  
measurement  
combinations.

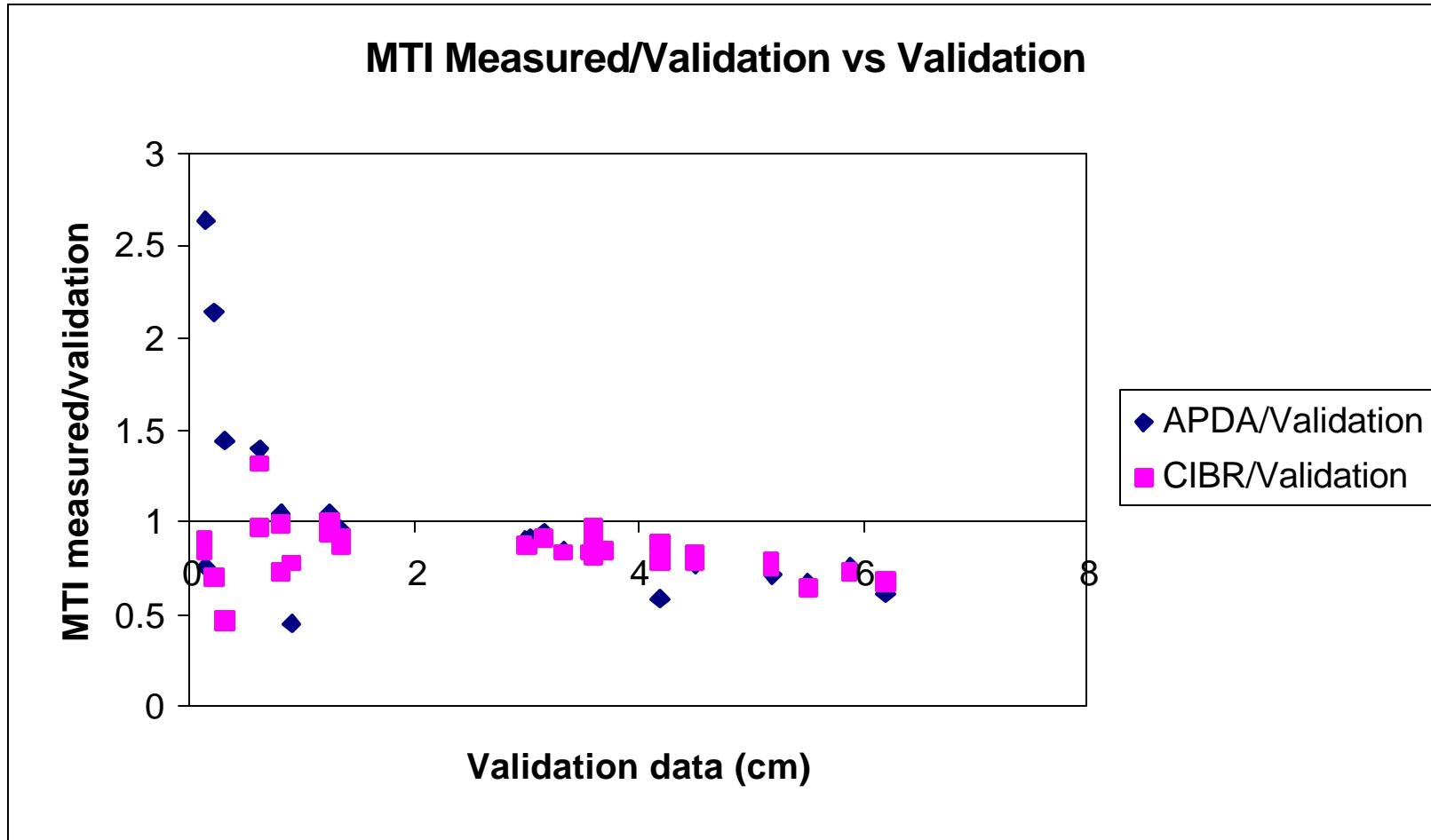
SITE	DATE	IMAGE ID	Solar Angle	Look Angle	APDA	CIBR	TRUTH	TYPE	% Diff. APDA	% Diff. CIBR
Ivanpah	09/15/00	29243	57.03	85.66	1.30	1.24	1.35	SRTC Balloon	-3.70%	-8.15%
Ivanpah	09/15/00	29243	57.03	85.66	1.30	1.24	1.24	sun photometer	4.84%	0.00%
Ivanpah	09/15/00	29250	57.11	31.69	1.23	1.18	1.35	SRTC Balloon	-8.89%	-12.59%
Ivanpah	09/15/00	29250	57.11	31.69	1.23	1.18	1.24	sun photometer	-0.81%	-4.84%
Ivanpah	09/16/00	29316	56.46	75.67	1.25	1.20	1.24	sun photometer	0.81%	-3.23%
Ivanpah	09/16/00	29323	56.52	31.45	1.26	1.19	1.24	sun photometer	1.61%	-4.03%
Mauna Loa	06/12/00	18498	81.36	85.27	0.15	0.15	0.32	Aeronet	-53.13%	-53.13%
Mauna Loa	06/12/00	18498	81.36	85.27	0.15	0.15	0.215	NOAA FSL Radiosonde	-30.23%	-30.23%
Mauna Loa	06/12/00	18505	80.92	31.75	0.46	0.15	0.32	Aeronet	43.75%	-53.13%
Mauna Loa	06/12/00	18505	80.92	31.75	0.46	0.15	0.215	NOAA FSL Radiosonde	113.95%	-30.23%
Mauna Loa	07/15/00	20926	85.88	61.89	0.86	0.81	0.82	Aeronet	4.88%	-1.22%
Mauna Loa	07/15/00	20926	85.88	61.89	0.86	0.81	0.82	JPL Radiosonde	4.88%	-1.22%
Mauna Loa	07/15/00	20926	85.88	61.89	0.86	0.81	0.615	NOAA FSL Radiosonde	39.84%	31.71%
Mauna Loa	07/15/00	20933	85.45	43.23	**	0.60	0.82	Aeronet	-26.83%	
Mauna Loa	07/15/00	20933	85.45	43.23	**	0.60	0.82	JPL Radiosonde	-26.83%	
Mauna Loa	07/15/00	20933	85.45	43.23	**	0.60	0.615	NOAA FSL Radiosonde	-2.44%	
Mauna Loa	10/09/00	31823	62.56	59.05	0.10	0.11	0.133	NOAA FSL Radiosonde	-24.81%	-17.29%
Mauna Loa	10/09/00	31830	62.61	23.44	0.35	0.12	0.133	NOAA FSL Radiosonde	163.16%	-9.77%
Nauru	05/19/00	17045	65.96	83.38	3.68	3.53	5.5	Aeronet	-33.09%	-35.82%
Nauru	07/02/00	20096	64.88	82.93	**	3.11	3.7	JPL Radiosonde	-15.95%	
Nauru	07/03/00	19774	64.21	73.26	3.43	3.30	4.2	Aeronet	-18.33%	-21.43%
Nauru	07/03/00	19781	63.94	32.42	2.42	3.73	4.2	Aeronet	-42.38%	-11.19%
Nauru	08/05/00	22793	71.54	73.79	4.46	4.32	5.9	Aeronet	-24.41%	-26.78%
Nauru	08/05/00	22800	71.30	33.79	**	4.26	5.9	Aeronet	-27.80%	
Stennis	06/02/00	17819	80.48	69.56	2.94	2.89	3.6	Aeronet	-18.33%	-19.72%
Stennis	06/02/00	17826	80.27	31.21	3.52	3.52	3.6	Aeronet	-2.22%	-2.22%
Stennis	07/29/00	22193	77.91	85.87	3.54	3.47	4.5	Aeronet	-21.33%	-22.89%
Stennis	07/29/00	22200	77.91	31.19	3.50	3.74	4.5	Aeronet	-22.22%	-16.89%
Stennis	08/10/00	23277	74.65	84.85	3.75	4.13	6.2	Aeronet	-39.52%	-33.39%
Stennis	08/10/00	23284	74.67	29.84	**	4.27	6.2	Aeronet	-31.13%	
Stennis	08/21/00	26240	71.39	73.98	3.73	3.90	5.2	Aeronet	-28.27%	-25.00%
Stennis	08/21/00	26247	71.47	29.70	**	4.10	5.2	Aeronet	-21.15%	
Point Barrow	10/12/00	32496	10.75	70.65	**	0.70	0.912	NOAA FSL Radiosonde	-23.25%	
Point Barrow	10/12/00	32503	10.87	31.44	0.41	0.70	0.912	NOAA FSL Radiosonde	-55.04%	-23.25%
SGP-ARM	08/24/00	26556	64.19	72.92	3.06	2.95	3.57	ARM Photometer	-14.29%	-17.37%
SGP-ARM	08/24/00	26563	64.30	29.93	3.35	3.15	3.59	ARM Photometer	-6.69%	-12.26%
SGP-ARM	08/25/00	26648	63.77	87.03	2.70	2.60	3.00	ARM Photometer	-10.00%	-13.33%
SGP-ARM	08/25/00	26655	63.85	30.68	2.78	2.60	3.03	ARM Photometer	-8.25%	-14.19%
SGP-ARM	08/26/00	26747	63.22	69.83	2.82	2.75	3.32	ARM Photometer	-15.06%	-17.17%
SGP-ARM	08/26/00	26754	63.28	30.37	3.01	2.92	3.16	ARM Photometer	-4.75%	-7.59%

\*\*failed to converge

\*ML Aeronet measurement from 3.3km, (all other ML from 4.1 km with retrievals at 4.1 km)

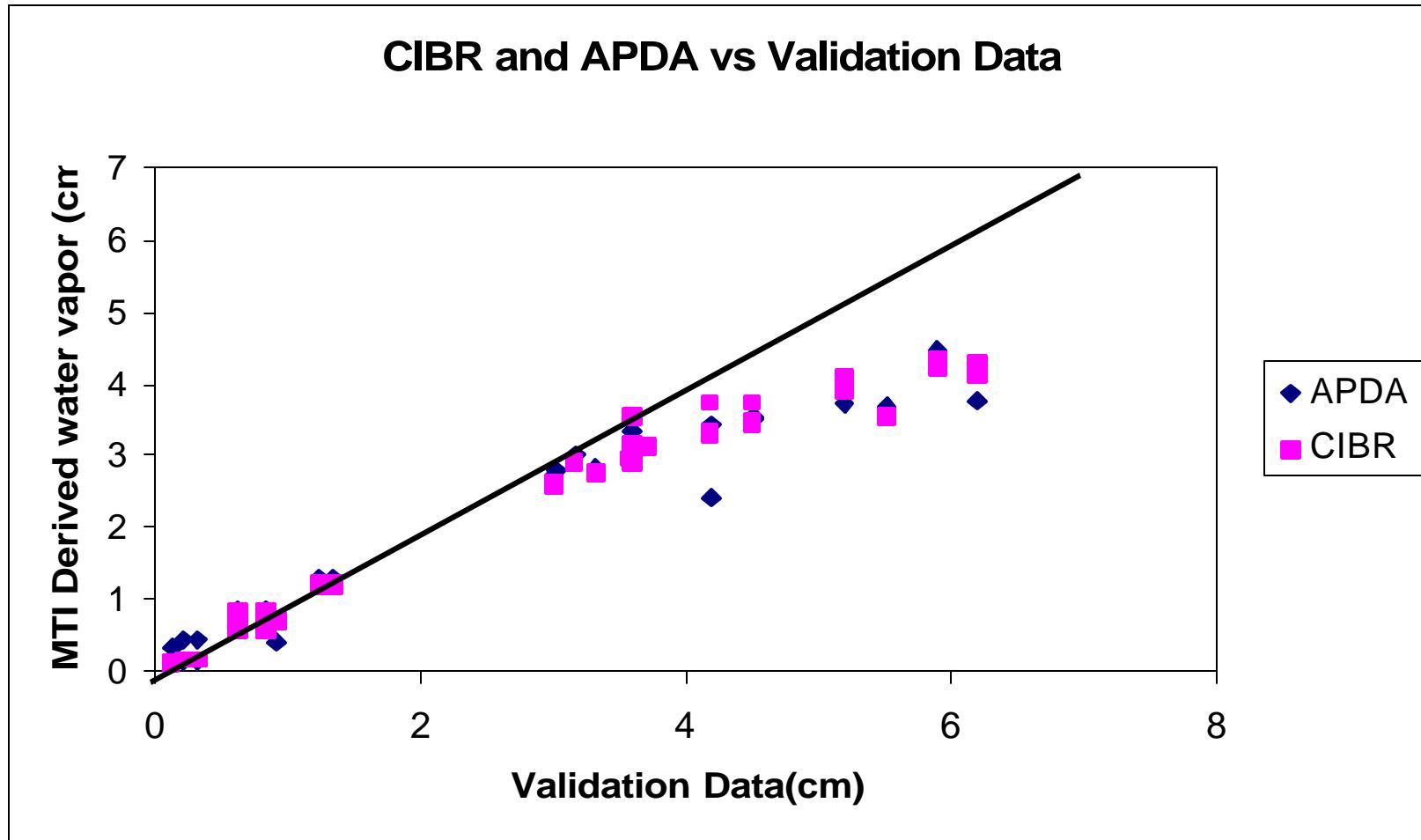


# Validation (cont'd):





## Validation (cont'd):

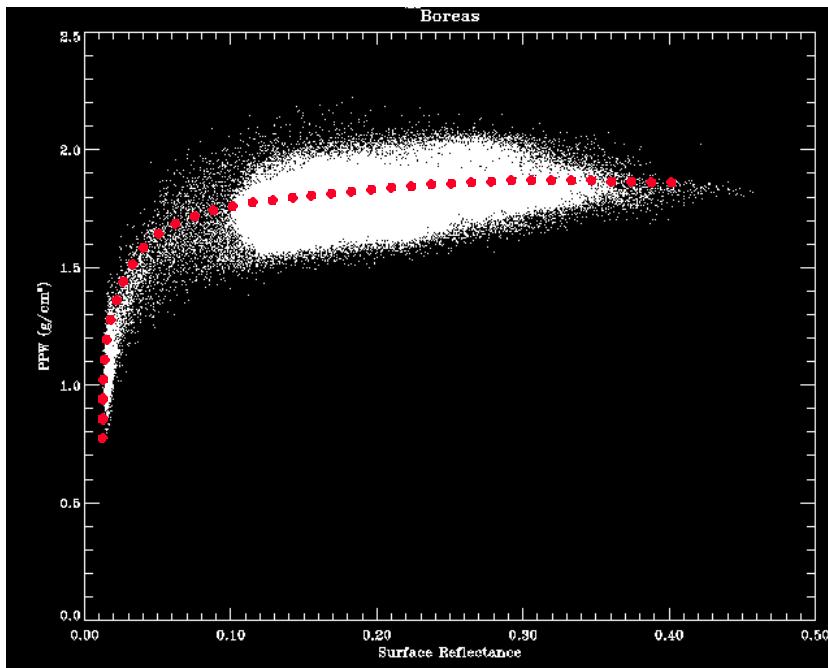




# Method 3: Curve fitting in CIBR

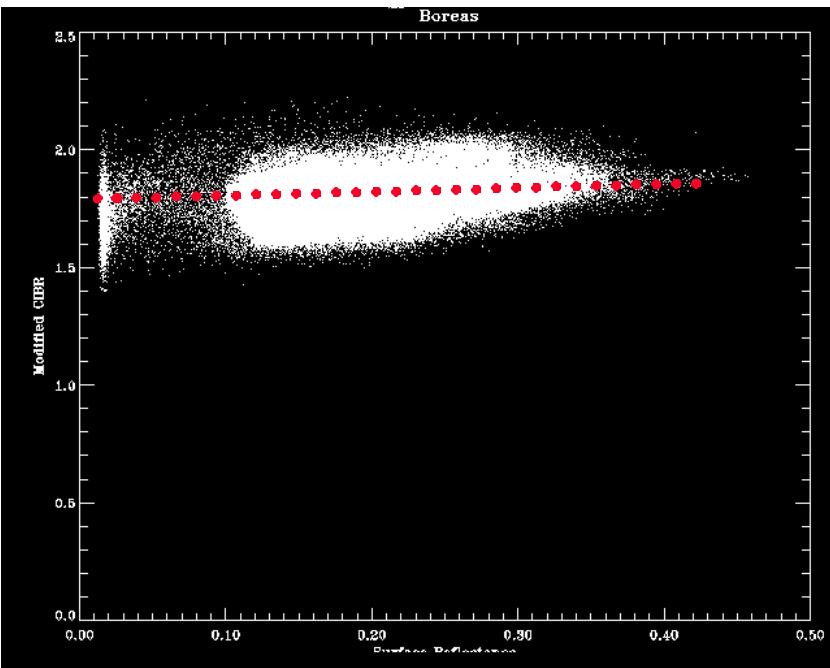
Before Fitting:

CIBR



Surface Reflectance

After Fitting:



Surface Reflectance



# Method 4: CIBR(PPW, Surface Reflectance)

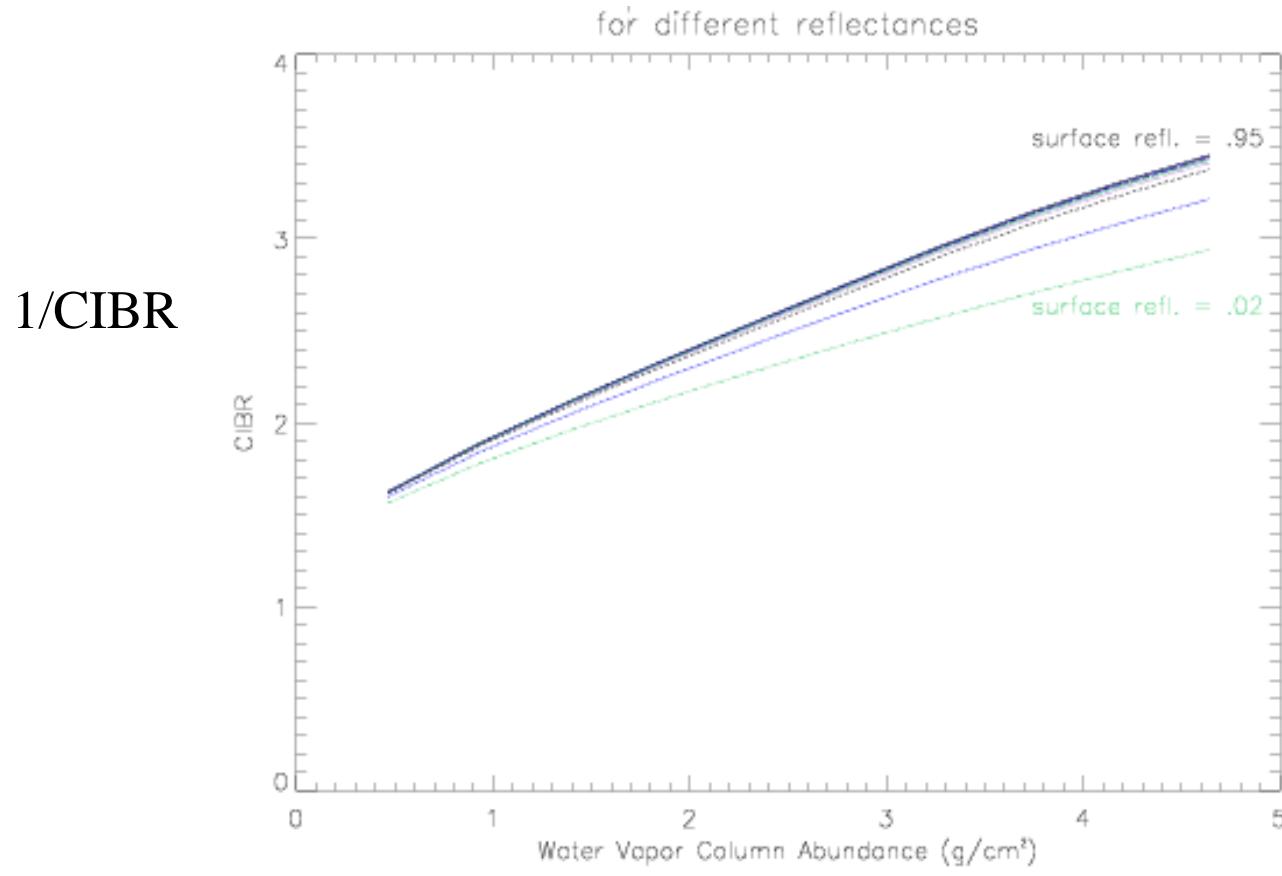
**Motivation:** want a CIBR that physically corrects for low reflectance pixels

- For 6 values of surface reflectance, create a look-up table of CIBR vs PPW
- For each pixel, nearest neighbor sample to one of those 6 values of surface reflectance, use the CIBR to discover the PPW



## Method 4 (cont'd):

Sample lookup table for inverse CIBR(surface reflectance, PPW)

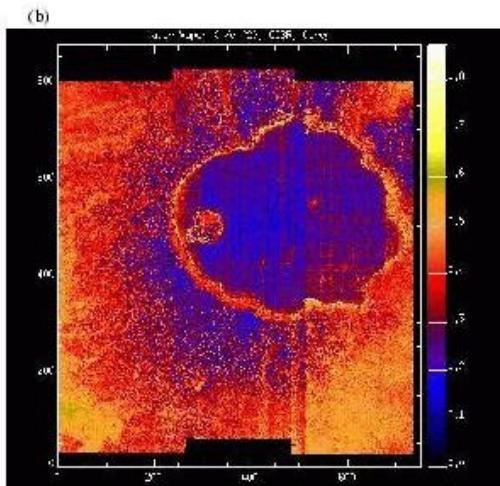
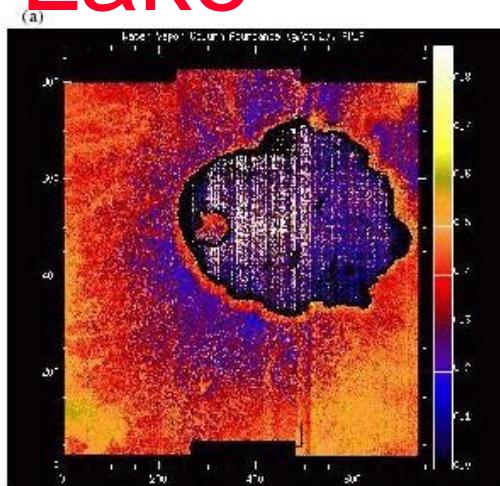


PPW



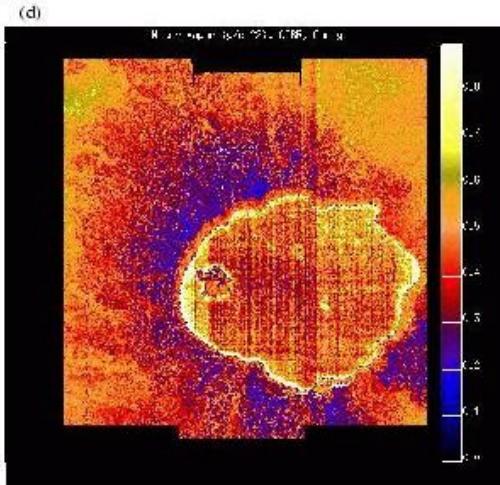
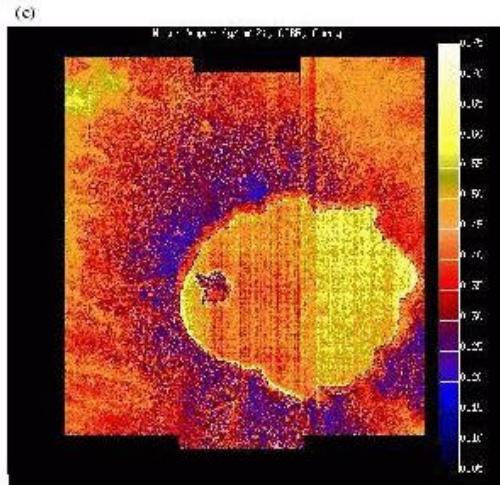
# Crater Lake

APDA



CIBR

CIBR  
+  
curve fit



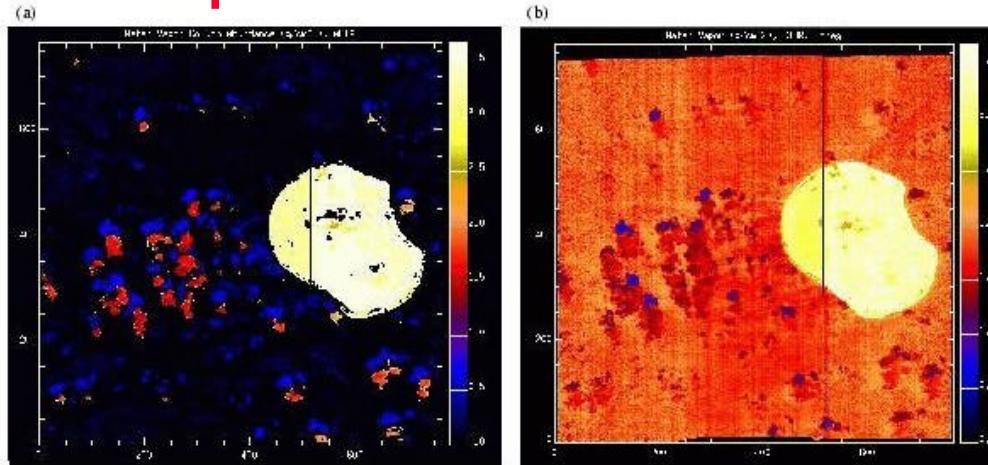
CIBR  
+  
 $f(\rho)$

PPW range 0-0.8 g/cm<sup>2</sup>



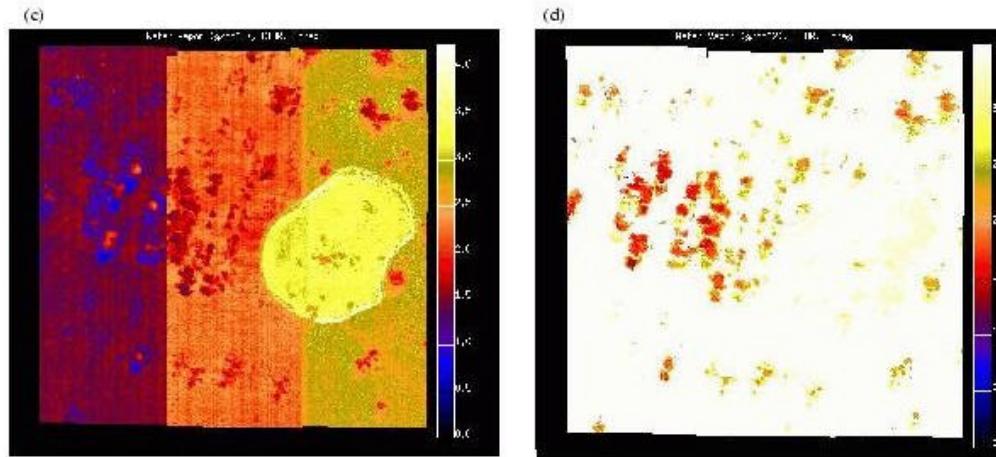
# Nauru – Tropical Western Pacific ARM Site

APDA



CIBR

CIBR  
+  
curve fit



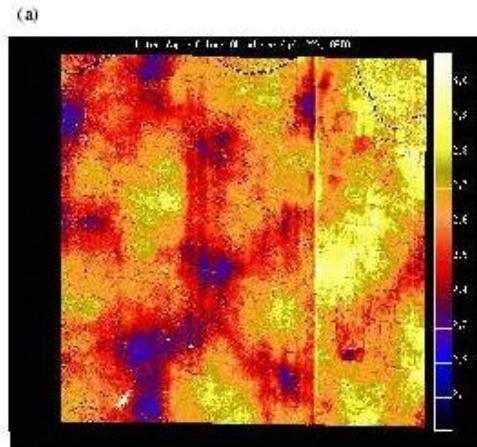
CIBR  
+  
 $f(\rho)$

PPW range 0-4.0 g/cm<sup>2</sup> - ground truth was 4.1 g/cm<sup>2</sup>

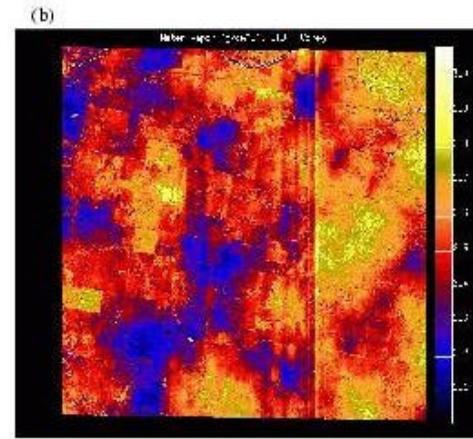


# Southern Great Plains ARM Site

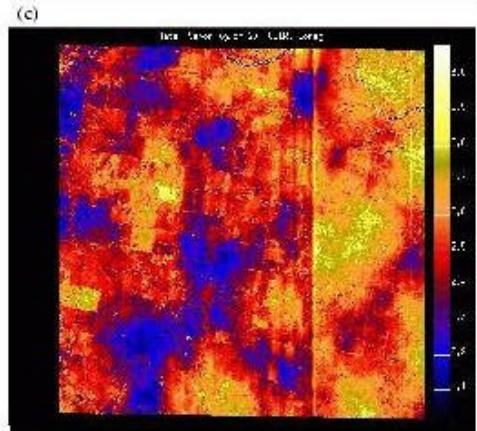
APDA



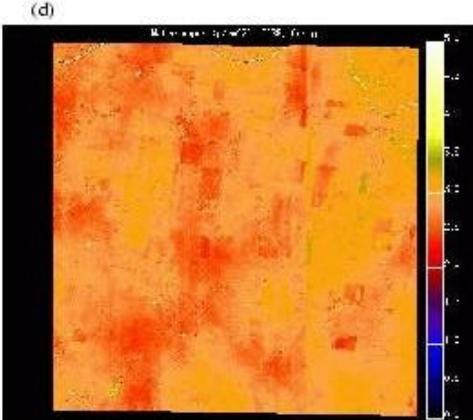
CIBR



CIBR  
+  
curve fit



CIBR  
+  
 $f(\rho)$



PPW range 3-3.6 g/cm<sup>2</sup>



## Conclusions

- All methods do a pretty good (within .5 cm) job at finding the amount of water vapor column abundance – especially in scenes where that abundance is less than 4 centimeters
- All methods can be automated – and in fact have been automated
- The CIBR as a function of surface reflectance returns the best results, but at a cost of 6 times the computer time



## Future Work

- Parallelize the CIBR as a function of surface reflectance.
- Quantify results using the new HITRAN database (this was run using MODTRAN 4 with the older version)